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Corrosion resistance of alloys of *Hastelloy* in chloroaluminate melts

The corrosion of Hastelloy S, Hastelloy X, Haynes 230, Hastelloy N, Hastelloy G35 and Hastelloy C2000 alloys was studied in KCl–$AlCl_3$ melts at 550°C. The rates and the mechanisms of corrosion of the studied materials were determined. The processes taking place during the interaction between alloys and chloroaluminate melts were investigated.

Introduction

Fast neutron energy reactors with molten salt coolant are related to a whole new generation of safe nuclear reactors where both uranium and thorium nuclear fuel can be used. However, the introduction of nuclear power plants based on molten salts is constrained by a number of problems; the most important of which is the need to develop new or improve existing structural materials, preserving stability in very aggressive conditions of high molten media.

The experimental part

This work is aimed at a comprehensive study of the interaction of high-temperature alloys Hastelloy S, Hastelloy X, Haynes 230, and corrosion-resistant alloys Hastelloy N, Hastelloy G35 and Hastelloy C2000 with chloroaluminate melts. Application of the latter is considered to be promising for the organization of the second coolant circuit of molten nuclear power plants. The corrosion behavior of the materials was studied at a temperature of 550°C in electrolytes KCl-$AlCl_3$, molar ratio Al: K equals 1:1. In this paper we used a set of independent research methods: gravimetric, metallographic analysis (Olympus GX-71F), electron microscopy and X-ray microanalysis (JSM 6490, ZEISS CrossBeam AURIGA). In addition to studying the structure of the test materials, chemical analysis of quenched samples after corrosion tests of electrolytes by atomic emission spectroscopy with inductively coupled plasma (Optima 2100DV) was carried out.

Results and discussion

The corrosion rates of the materials in molten KCl-$AlCl_3$ at a ratio of Al/K = 1.1 after 100 hours at 550 °C are given in Table 1.

We found that heat-resistant alloys Hastelloy X, Hastelloy S and Haynes 230 after exposure to chloaluminates melts are subject to intergranular corrosion (ICC). Under metallographic corrosion (1) of corroded samples, on their surface continuous chains of secondary excess phases at the grain boundaries are clearly observed (Figure 1).

The results of X-ray microanalysis demonstrated that along the chromium grain boundary, chromium concentration decreases by 20%, but directly at the grain boundaries increases dramatically. In heat-resistant melts the process of carbides formation on grain boundaries occurs primarily as a result of 'rebirth' of carbides due to heat powert (2):

$$6Me_6C + nCr = Me_{23-n}Cr_nC_6 + (13 + n)\,Me,$$

This leads to the formation and subsequent dissolution of microgalvanopars and their anodic areas. These processes cause the development of these alloys, such as "Hastelloy" processes ICC.

Thus, despite the relatively low integral corrosion rate superalloy Hastelloy X,

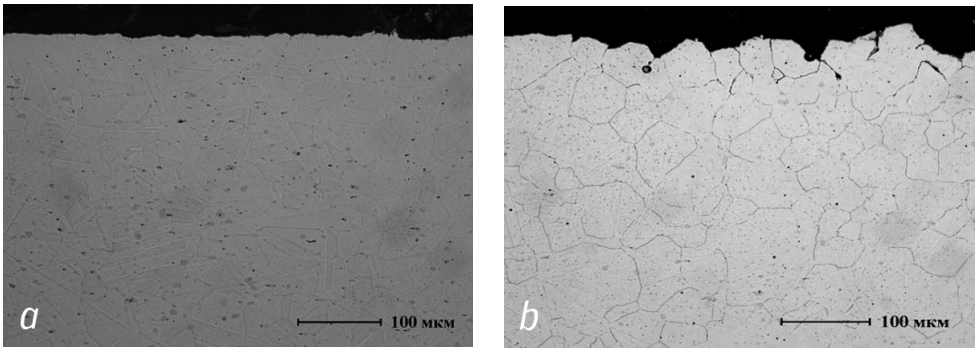

Fig. 1. The formation of excessive phase in the alloy Hastelloy X after contact with a melt KCl-$AlCl_3$ for 100 hours at 550°C. (*a* – delivery status, *b* – after exposure to molten electrolyte)

Table 1

The rate of corrosion of alloys such as "Hastelloy" in KCl-$AlCl_3$ melt at 550°C.

Brand	Corrosion speed		Depth of corrosion penetration, μm
	g / (m^2×h)	mm / year	
X	0.8±0.2	0.9±0.2	55–65
S	0.8±0.1	0.8±0.1	18–24
230	0.8±0.2	0.8±0.2	27–32
N	0.6±0.1	0.6±0.1	–
G35	1.4±0.3	1.4±0.3	–
C2000	1.6±0.3	1.7±0.3	–

Hastelloy S and Haynes 230 chloraluminated electrolytes at 550°C, their use as structural materials in these conditions is not recommended due to the propensity to the ICC.

Character of surfaces fracture of corrosion-resistant nickel-chromium-molybdenum alloys (Hastelloy N, Hastelloy G35, Hastelloy C2000) after exposure to KCl-$AlCl_3$ at 550°C is solid, uneven (Fig. 2).

The existing local areas of increased corrosion are associated with structural unevenness of materials and presence of defective zones. Metallografic analysis and etching to detect intergranular segregation show that after 100 hours exposure of the samples, secondary phases at grain boundaries are small and fragmented (Figure 3). Increasing the concentration of existing inclusions in the bulk samples is also not revealed. Corrosion rate of alloys Hastelloy N, G35 and C2000 is defined by redox processes, as a result of which the ions of sal medium oxidize the most electronegative alloy components such as chromium, manganese and iron.

Conclusions on the preferential dissolution during exposure in the melt KCl-$AlCl_3$ of the most electronegative component of alloys Hastelloy N, Hastelloy G35 and Hastelloy C2000 (chromium, manganese and iron) are confirmed by the data of chemical analysis of frozen electrolyte melts obtained after corrosion tests. Longer contacts with the chloraluminated electrolytes to 500–1000 hours result in a significant reduction of the corrosion rate of studied corrosion resistant alloys "Hastelloy". On the one hand this is due to slow diffusion of electronegative alloy components of the grains of the boundary electrolyte – melt, and low rate of removal of the corrosion products from a melt saturated by these elements. Furthermore, we recorded the alloy surface

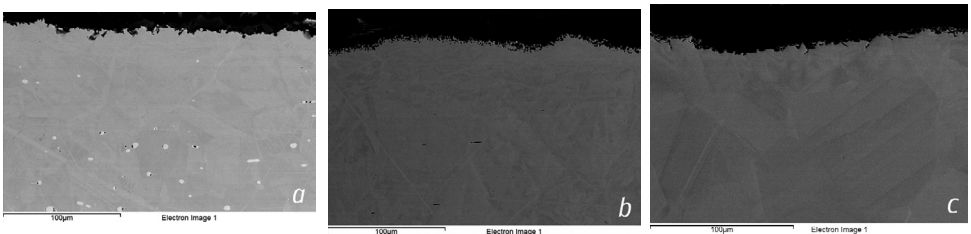

Fig. 2. The microstructure of the alloy specimens after 100 hours exposure in the KCl-$AlCl_3$ at 550°C (*a* – Hastelloy N, *b* – Hastelloy G35, in – Hastelloy C2000)

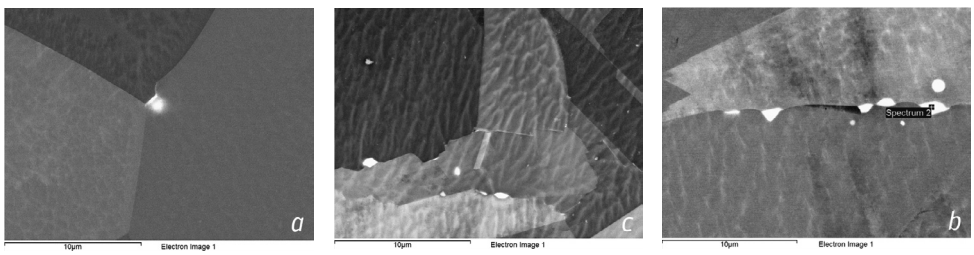

Fig. 3. Formation of excess phases in corrosion-resistant nickel alloys after 100 hours exposure in KCl-$AlCl_3$ at 550°C (*a* – Hastelloy N, *b* – Hastelloy G35, in – Hastelloy C2000)

layer formation of non-corrosive components - molybdenum and nickel. It can be reasonably assumed that the image in the corrosion coating may have a protective effect and protect the structural material from further destruction.

Thus, using of corrosion-resistant nickel-chromium-molybdenum alloys (Hastelloy N, Hastelloy G35, Hastelloy C2000), it is possible to predict quantitatively the corrosion processes. It is without doubt that the interest to study the possibility of organizing the protection of materials due to the "self-passivation" electropositive surface of the alloy components will exist.

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